ÚÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄ¿
³ NOTICE OF INACTIVE ³
³ FOR NEW DESIGN   ³
ÀÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÙ

ÚÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄ¿
³ INCH-POUND   ³
ÀÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÄÙ

MIL-HDBK-1005/2
NOTICE 1
09 May 1997

DEPARTMENT OF DEFENSE
HANDBOOK

HYDROLOGY

MIL-HDBK-1005/2, dated 30 June 1990, and any subsequent revisions or change notices are inactive for new design and shall be no longer used as a guidance reference for new designs.

Custodian:
Navy - YD2

Preparing Activity:
Navy - YD2
(Project FACR-0761)

AMSC N/A

AREA FACR

Military Handbook 1005/2
June 30, 1990
Notice 1
9 May 1997
CCB #41 Third Quarter 1997

CCB Application Notes:

1. Character(s) preceded & followed by these symbols (À Ù) or (Ú ¿) are super- or subscripted, respectively.
   EXAMPLES: 42mÀ3Ù = 42 cubic meters
   COÚ2¿ = carbon dioxide

2. All degree symbols have been replaced with the word deg.

3. All plus or minus symbols have been replaced with the symbol +/-.

4. All table note letters and numbers have been enclosed in square brackets in both the table and below the table.

5. Whenever possible, mathematical symbols have been replaced with their proper name and enclosed in square brackets.

MIL-HBDK-1005/2
30 JUNE 1990
Superseding
DM-5.02
SEPTEMBER 1985

MILITARY HANDBOOK

HYDROLOGY

AMSC N/A AREA FACR

ABSTRACT

This military handbook provides design guidance for use by engineers for hydrologic studies and computations. The topics include computer applications, surface water and groundwater resources development, inland flooding and drainage, coastal flooding and drainage, interior drainage of leveed areas, and runoff methodologies. This handbook also includes a glossary, list of references, and the sources of hydrologic data.

FOREWORD

This military handbook is one of a series developed from an evaluation of facilities in the shore establishment, from surveys of the availability of new materials and construction methods, and from selection of the best design practices of the Naval Facilities Engineering Command (NAVFACENGCOM), other Government agencies, and the private sector. This handbook uses, to the maximum extent feasible, national professional society, association and institute standards in accordance with NAVFACENGCOM policy.

Recommendations for improvement are encouraged from within the Navy, other Government agencies, and the private sector and should be furnished on the DD Form 1426 provided inside the back cover to Commander, Atlantic Division, Naval Facilities Engineering Command, Code 04A4, Norfolk, VA 23511-6287; commercial telephone (804) 444-9970.

THIS HANDBOOK SHALL NOT BE USED AS A REFERENCE DOCUMENT FOR PROCUREMENT OF FACILITIES CONSTRUCTION. IT IS TO BE USED IN THE PURCHASE OF FACILITIES ENGINEERING STUDIES AND DESIGN (FINAL PLANS, SPECIFICATIONS, AND COST ESTIMATE). DO NOT REFERENCE IT IN MILITARY OR FEDERAL SPECIFICATIONS OR OTHER PROCUREMENT DOCUMENTS.

CIVIL ENGINEERING DESIGN MANUALS

Criteria Manual	Title	PA
DM-5.01	Surveying	LANTDIV
MIL-HDBK-1005/2	Hydrology	LANTDIV
MIL-HDBK-1005/3	Drainage Systems	LANTDIV
DM-5.04	Pavements	PACDIV
DM-5.06	Trackage	NORTHDIV
MIL-HDBK-1005/7	Water Supply Systems	SOUTHDIV
MIL-HDBK-1005/8	Domestic Wastewater Control	NEESA
MIL-HDBK-1005/9	Industrial and Oily Wastewater Control	HDQTRS
DM-5.10	Solid Waste Disposal	PACDIV
MIL-HDBK-1005/12	Fencing, Gates, and Guard Towers	WESTDIV
MIL-HDBK-1005/13	Hazardous Waste Storage and Transfer	HDQTRS
DM-5.14	Groundwater Pollution Control	HDQTRS

HYDROLOGY

CONTENTS

FIGURES

TABLES

Section 1: INTRODUCTION

1.1 Scope. MIL-HDBK-1005/2 addresses the criteria, computational methodology, references, and sources of information relating to hydrology. This handbook is subdivided into the following general categories:

a) Water Resources Development

b) Inland Flooding and Drainage

c) Coastal Flooding and Drainage

d) Interior Drainage of Leveed Areas

e) Runoff Prediction Methodologies

f) Sources of Data

1.2 Application. This handbook is to be used by designers for hydrologic computations and analysis. It is a guide to select the appropriate computational methodology and to define hydrologic design criteria.

1.3 Guidelines for Computer Applications. Computer programs help to define the problem and analyze alternate solutions. The value and accuracy of computer modeling results are dependent upon the user's understanding of the program methodology and the quality of the input data. Numerous computer programs exist that may aid the designer in all types of hydrologic analyses.

Use the following guidelines for computer applications:

a) Select programs that are well documented with examples of applications similar to those needed for the project.

b) If available, use historic data or field measurements to calibrate computer models.

c) If input data can vary over a wide range, perform a sensitivity analysis to identify the impact that variations in input data may have on the results of the computer analysis.

d) Precise computations may give the designer a false sense of accuracy of the results. Have an understanding of the expected accuracy of the results and the methodology used.

1.4 Cancellation. This handbook, MIL-HDBK-1005/2, dated 30 June 1990, cancels and supersedes NAVFAC DM-5.02, Hydrology, dated September 1985.

Section 2: WATER RESOURCES DEVELOPMENT

2.1 Water Resources Development. MIL-HDBK-1005/2 addresses only water quantity prediction relating to these uses. Refer to MIL-HDBK-1005/7, Water Supply Systems, for information and criteria on quality, utilization, and distribution.

Water resources development is subdivided into two general topics: surface water supply and groundwater supply. Each topic includes special considerations that use hydrologic methods for the prediction of water quantity.

2.2 Surface Water Supply. General procedures are shown in Figure 1.

2.2.1 Potential Yield of Rivers and Streams. Local authorities may have stream flow records useful for statistical analysis to determine average and minimum daily, monthly, and annual flow rates. Refer to Section 7 for sources of stream flow data. Statistical methods may be found in the hydrology texts.

a) Base Flow Prediction. For empirical and graphical methods of base flow prediction, refer to the following texts: Hydrology for Engineers, R. K. Linsley, M. A. Kohler, and J. L. H. Paulhus, 1982, Chapter 7, and Handbook of Applied Hydrology, V. T. Chow, 1964, Section 14.

b) Design Criteria. Refer to MIL-HDBK-1005/7 for water supply requirements. Arrange with local authorities to provide for priority of water usage rights and minimum downstream discharges. Refer to NAVFAC Publication P-73, Real Estate Procedural Manual, for rights and agreements pertaining to military ownership water supplies.

2.2.2 Potential Yield of Reservoirs. Comprehensive references are published by the Hydrologic Engineering Center (HEC), U.S. Army Corps of Engineers. Refer to HEC, Hydrologic Engineering Methods for Water Resources Development, Chapters 4, 5, 6, and 7, and Volume 1, Requirements and General Procedures.

a) Water-Budget Analysis and Design Criteria. Water-budget analysis is used to determine the relationship between reservoir storage and reservoir yield (supply). Refer to HEC, Volume 8, Reservoir Yield, Chapter 6. This reference covers the selection and analysis of available data, the use of generalized and simulated data, and the application of technical procedures.

b) Water Demand Design Criteria. Refer to MIL-HDBK-1005/7 for determination of water demands and water supply requirements.

2.3 Groundwater Supply. Two comprehensive general references are HEC, Volume 10, Principles of Groundwater Hydrology; and Groundwater Hydrology, D. K. Todd, 1980. For a less technical reference use the U.S. Department of Agriculture, Soil Conservation Service (SCS), Engineering Field Manual, Chapter 12.

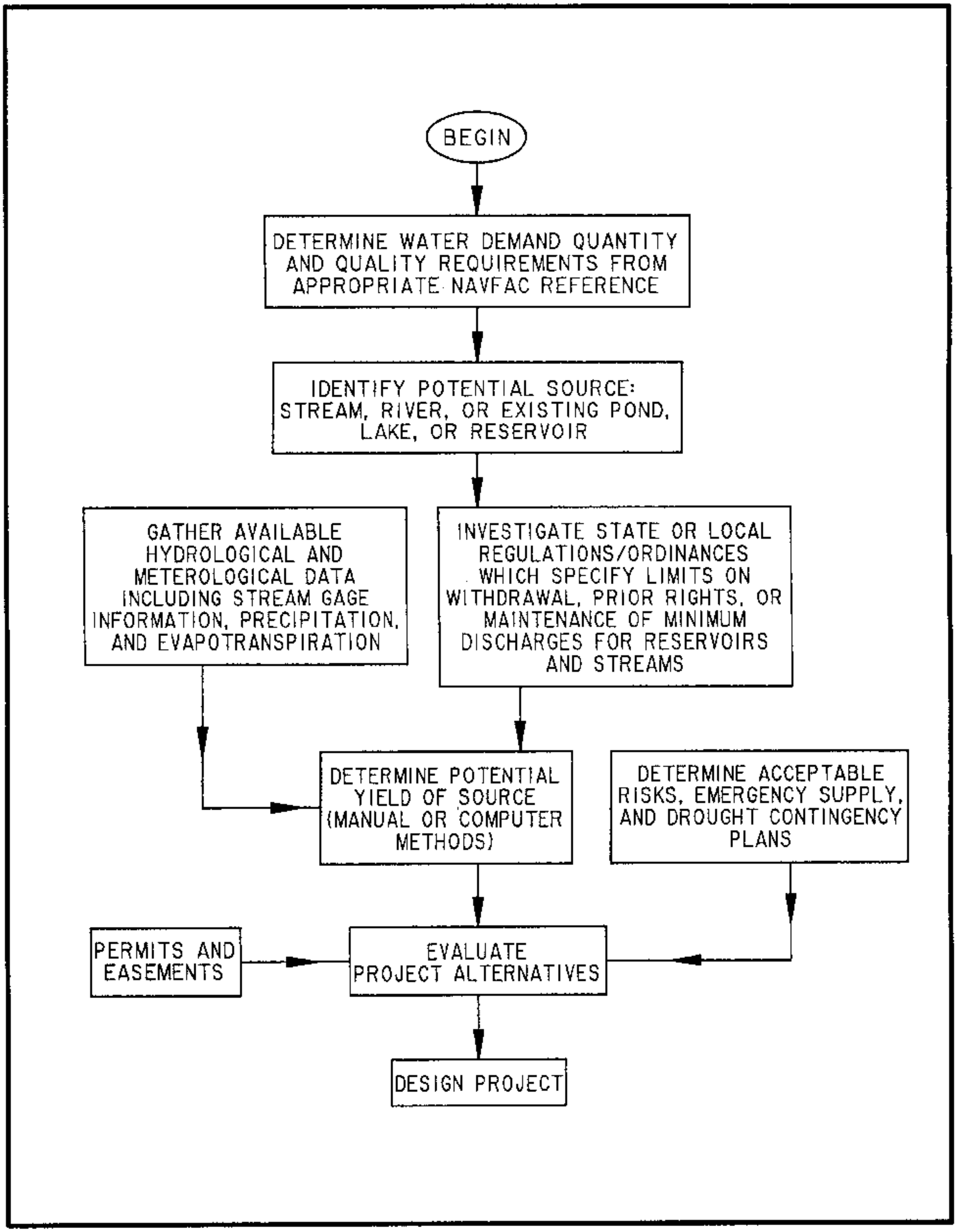

Figure 1
Surface Water Supply--General Procedures

2.3.1 Potential Yield of Aquifers. For the potential yield of aquifers in various types of strata see HEC, Volume 10, Principles of Groundwater Hydrology, Chapters 10, 11, and 12. These chapters discuss the occurrence of groundwater in igneous and metamorphic rock, sedimentary rock, and unconsolidated earth materials, respectively.

a) Geologic References. Geological data and determination of groundwater availability are essential elements for aquifer development. Individual state geological surveys, state bureaus of mines, universities, colleges, local geologists, and companies which construct wells may provide important reference materials including test well data, maps, and reports. Test well data for the continental United States, Alaska, and Hawaii is available from the U.S. Geological Survey (USGS). Refer to USGS Circular No. 856, Storage and Retrieval of Groundwater Data at the USGS.

b) Field Investigations--Test Wells. Pumping tests are made to estimate the most economical and dependable water yield from a specific well or well field. For the design of groundwater supplies, the combination of discharge and drawdown provides the most economical and dependable solution. SCS, Engineering Field Manual, Chapter 12, Section 7, "Well Site Selection," is a good general reference. More sophisticated, indirect subsurface investigation methods are described in HEC, Volume 10, Chapters 8 and 9. These include gravity, magnetic, electric, and seismic surface investigation methods, as well as several subsurface groundwater tracing methods. Base the design of water supply wells upon one test well at each well site completed with soil logs and drawdown curves.

2.3.2 Recharge of Aquifer. Due to scarcity of groundwater supplies in some areas, local jurisdictions may limit the amount of water drawn from an aquifer to the amount recharged naturally by infiltration and artificially by recharge wells. Check with local authorities for recharge requirements.

a) Infiltration. Factors that influence the rate of infiltration include permeability of the soil, storage capacity, initial moisture content, depth to groundwater table, temperature of soil, and land cover. Refer to Chow, 1964, Section 12.

b) Artificial Recharge. Artificial recharge through the use of wells, basins, ditches, and surface applications is used to replace groundwater resources, prevent land subsidence, and prevent saltwater intrusion. Refer to Todd, 1980, Chapter 13.

2.3.3 Saltwater Intrusion. Sources of groundwater may be in close proximity to the sea, to natural bodies of saline groundwater, or to salts from effluent wastes; if any of these conditions exist, sources of groundwater are subject to saltwater intrusion. If the groundwater storage in the aquifer is small, excessive pumping may be disastrous to any economy dependent on the aquifer for water. Excessive lowering of the groundwater table may result in contamination of groundwater by inflow of undesirable waters. Methods for controlling intrusion include modifications to pumping patterns, barriers, artificial recharges, or relocation of wells. Refer to Todd, 1980, Chapter 14, "Saline

Water Intrusion in Aquifers."

2.4 Drought. The planning of water supplies, either surface water or groundwater types, includes planning to prepare for droughts. Consider the following:

a) Consumer Alert. Plan for an information program utilizing fliers, newspapers, radio, and signs to inform consumers regarding emergency water conservation measures.

b) Emergency Sources. Provide interconnections and agreements with neighboring jurisdictions for emergency supplies.

c) Coordinate Actions. Prepare a list of actions that will be required as the severity of the drought increases.

Section 3: INLAND FLOODING AND DRAINAGE

3.1 Inland Flooding and Drainage. MIL-HDBK-1005/2 divides the topic of inland flooding and drainage into two categories. The first, Flood Plain Management, addresses hydrologic methods and procedures used to identify flooding hazards and to evaluate flood protection measures. The primary intent of this category is to provide the designer with the means to generate peak flow rates for watersheds of 2 square miles or more. Storm Water Management, the second category, addresses watersheds of less than 2 square miles. The separation at 2 square miles, although not universal, is a practical limit for the reduction of peak rate or volume of storm water runoff using onsite storage or infiltration methods. It is also a valid separation for applications for which direct peak runoff equations are practical and for which hydrograph or other methods should be employed.

3.2 Flood Plain Management. Use the general procedures for flood plain management shown in Figure 2 where Government facilities exist or are planned within or adjacent to a flood plain with a contributing drainage area greater than 2 square miles. When site approval of a facility is granted by planning, evaluate the following measures, and if corrective or mitigating features are required in a project, address them in the project documents.

3.2.1 Sources of Available Flood Delineation Mapping. The U.S. Army Corps of Engineers (COE), the Federal Emergency Management Agency (FEMA), and various local planning agencies have delineated the flood plains of many rivers and streams. These maps are available upon request from the agencies listed in Section 7.

a) Determining Map Accuracy. If existing flood limit maps are used, inquire as to the expected accuracy of the map information and determine if that accuracy is consistent with the design requirements of the project. Assess the potential changes in the flood limits which may be caused by future development of the watershed. Future development has greater potential impact on smaller watersheds.

3.2.2 Historical Data and Gage Records. Obtain historical data on floods where available. Information sources include USGS, state geologic surveys, and local newspaper files. Refer to Section 7 for sources of stream gage records. A comprehensive reference for developing peak flood flow rates from gage records is HEC, Volume 3, Hydrologic Frequency Analysis. It includes general probability concepts, computation of frequency curves, development effects on flood frequencies, and regional transfer of frequency statistics. A more general coverage of gage-frequency analyses methodology can be found in most hydrology texts such as Linsley, Kohler, and Paulhus, 1982, Chapter 11, "Frequency and Duration Studies." Computer models are available for stream gage flood frequency computations (refer to Section 6). USGS has prepared stage and discharge frequency relationships for many of its gaging stations (see Section 7).

a) Flood Flow Frequency Analysis. Refer to U.S. Water Resources Council, Guidelines for Determining Flood Flow Frequency, Bulletins 17 and 17A.

3.2.3 Regional Equations. Local agencies, such as state departments of transportation and water resources, universities, and regional planning agencies, may have derived regression equations for runoff frequency and rainfall-runoff relationships for generalized watersheds within their region.

Use regional equations, if available, only for preliminary estimates of stream flow.

3.2.4 Rainfall/Runoff Models and Unit Hydrograph Methods. If less than 15 years of stream gage records are available, or if none exist, which is often the case, derive the peak stream flow rates using a rainfall/runoff model. Rainfall/runoff models require acquisition of rainfall frequency data, land use, topographic, and soils data for the watershed. Refer to Section 6 for both manual methods for determining runoff and for computer runoff models.

a) Unit Hydrographs. Derive a unit hydrograph from gage information or watershed parameters to predict runoff from precipitation. Most hydrology texts discuss the derivation of unit hydrographs from stream flow records. Unit hydrographs vary with location within the watershed. To adjust a unit hydrograph developed for a gage location for use in another portion of the basin, use the Clark Method. A comprehensive reference for the Clark Method, as well as unit hydrograph theory, is covered in HEC, Volume 4, Hydrograph Analysis. The Clark Method is included in the computer program HEC-1 (see Table 3).

b) Synthetic Unit Hydrographs. Several methods are available to construct synthetic hydrographs without gage information. Two popular methods for deriving synthetic unit hydrographs are the Snyder Method and the SCS dimensionless unit hydrograph method. Refer to Linsley, Kohler, and Paulhus, 1982, Chapter 9, for a description of the HEC-I computer program which includes the Snyder Unit Hydrograph Method as well as several others. The SCS dimensionless unit hydrograph method is discussed in the SCS, National Engineering Handbook, Section 4, "Hydrology." The computer programs TR-20 and HEC-1 include the SCS dimensionless unit hydrograph method.

c) Hydrograph Routing. Combine and route hydrographs through reaches or reservoirs using the methods listed in Table 1.

3.2.5 River-Tributary Combined Flooding. The flooding of a river and its tributaries may occur under a variety of conditions based on the timing of the tributary and main stream hydrographs. Refer to paragraph 3.2.4.

3.2.6 Flood Protection Measures. Flood protection measures fall into two general categories: structural and nonstructural.

a) Structural. Structural measures include floodwalls, stream channel capacity enhancement, levees and dikes, and closed-conduit systems. Refer to MIL-HDBK-1005/3 for references and criteria on these systems.

b) Nonstructural. Nonstructural measures for existing facilities include relocation, floodproofing, and flood warning systems. Planned facilities shall not be located within specified flood hazard limits (see MIL-HDBK-1005/3) unless they are temporary or capable of withstanding flooding without structural damage. Several references on nonstructural flood protection measures are available from the U.S. Army Corps of Engineers. These include:

HEC, Estimating Costs and Benefits for Nonstructural Flood Control Measures, W. D. Carson, 1975.

HEC, Annotations of Selected Literature on Nonstructural Flood Plain Management Measures, H. J. Owen, 1977.

U.S. Army COE, Cost Report on Non-Structural Flood Damage Reduction Measures for Residential Buildings Within the Baltimore District.

The Application of Nonstructural Measures to Coastal Flooding, P. B.

Cheney and H. C. Miller, 1975.

3.3 Storm Water Management. Storm water management is the control of storm water runoff for the prevention of minor flooding, stream erosion, and sediment deposition. For Government facilities, storm water management encompasses runoff computation methods and rate and volume control methods for drainage areas under 2 square miles. For degrees of protection for various facilities, refer to Table 2 entitled "Facility Degree of Protection (Years)" in MIL-HDBK-1005/3. Refer to SCS, Engineering Field Manual, Chapter 11, for design criteria and methodologies used in all aspects of pond development.

3.3.1 Department of Defense Environmental Protection Criteria. General environmental protection criteria are found in MIL-HDBK-1190, Facility Planning and Design Guide.

3.3.2 Fundamental Concepts of Storm Water Management. An increase of impervious area due to development causes an increase in both volume and peak rate of storm water runoff. Reduction of travel times due to drainage system improvements and reduction of natural storage areas due to grading cause an increase of peak runoff rate. In addition to rate and volume increases, urban and agricultural activities generate an increase of pollutant loadings in receiving streams. Storm water management measures are designed to mitigate these impacts.

3.3.3 Hydrologic Design of Small Drainage Systems. Use the computational methodologies listed in Section 6 to develop peak storm water flow rates for the design of small drainage systems. Refer to hydraulic design and component criteria given in MIL-HDBK-1005/3.

3.3.4 Detention Outlet Control Structures. Refer to American Society of Civil Engineers (ASCE), Book No. 480, Storm Water Detention Outlet Control Structures.

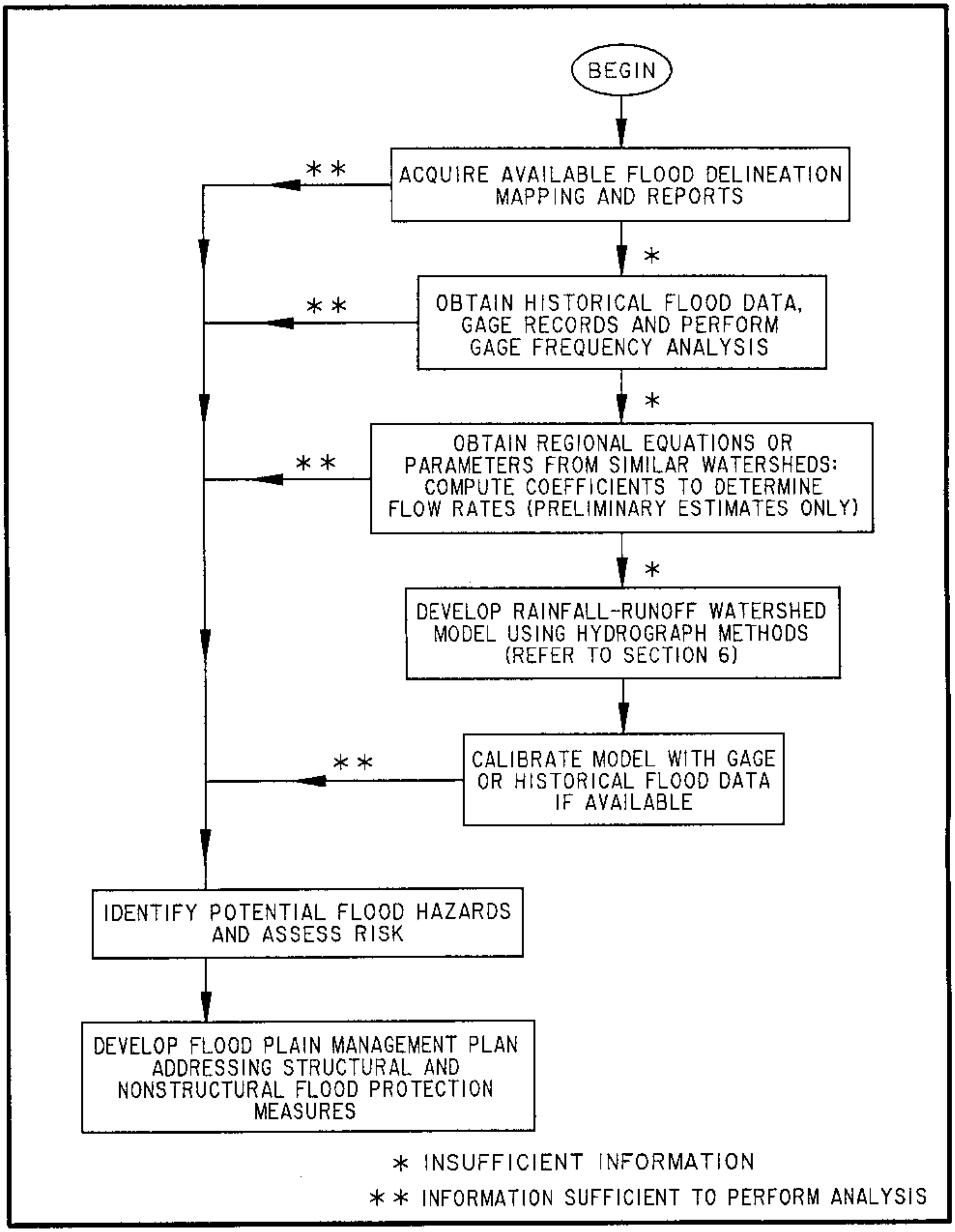

Figure 2
Flood Plain Management Flow Chart

Table 1
Hydrograph Routing Procedures

Method	Application	Data Requirements	Limitations	References
Modified-Puls (Storage Indicator)	Reservoirs, ponds, level-pool storage	Inflow hydrograph, stage-discharge and stage-storage volume curves, initial storage, routing interval.	Not generally used for channel routing but can be adapted for this use	SCS, National Engineering Handbook, NEH-4, Section 4, Ch. 17
Mass-Curve	Reservoirs, ponds, level-pool storage	Inflow mass curve (accumulated inflow), stage-discharge, stage-storage relationships	Approximate method not suited for open-channel routing	SCS, NEH-4, Ch. 17 Dept. of Interior, Bureau of Reclamation, Design of Small Dams
Muskingum	Open channels	Inflow hydrograph, travel time through reach, storage coefficient	Requires two empirical coefficients derived from field data or estimated	COE, EM 1110-2-1408 Routing of Floods Through River Channels, and Linsley, Kohler, Ch. 10
Working Value	Open channels, graphical method	Inflow hydrograph, channel storage-stage curve. Muskingum storage coefficient	Not suited for reservoir routing	Chow, 1964, Section 25-II
Average Lag	Open channels	Inflow hydrograph, routing constants, lag interval	Approximations, not based on mathematical relationships. Not suited for routing	COE, EM-1110-2-1408 and Chow, 1964.

Table 1 (Continued)
Hydrograph Routing Procedures

Method	Application	Data Requirements	Limitations	References
Convex	Open channels	Inflow hydrograph, channel cross-sectional area vs. discharge or average velocity	Routing coefficient dependent on reach length. Not suited for reservoir routing	NEH-4, Ch. 17
Modified ATT-KIN	Open channels	Inflow hydrograph, channel cross-sectional area vs. discharge curve or coefficients	Not suited for reservoir routing	SCS, _Computer Program for Project Formulation Hydrology_,

3.3.5 Local Storm Water Management Ordinances. Several basic concepts of local storm water management laws and regulations exist throughout the United States. Basic concepts which are likely to be encountered include:

a) Peak Rate Control--Local Basins. This type of ordinance specifies that postdevelopment peak storm water runoff rates be maintained at some pre-development level. This is most frequently accomplished through the use of detention basins or storage ponds. The intent of this ordinance is to mitigate the effects of urbanization on receiving streams by controlling storm water runoff rates. Such ordinances ignore the runoff volume increase and quality deterioration associated with development. This type of ordinance also ignores the basin-wide impact of the construction of numerous onsite storm water management basins which may result in combined hydrographs from tributaries that produce greater peak discharge than in the unmanaged state.

b) Peak Rate Control--Regional Basins. A second generation ordinance has evolved in a few jurisdictions that proposes to control storm water runoff rates through the use of offsite or regional basins. Although the basin-wide impacts are usually identified for these regional ponds, the volume and quality issues are not addressed. Additionally, the extended bank-full flows resulting from the delayed release of stored storm water in large regional ponds could promote erosion in outfall streams.

c) Volume and Quality Control. Some storm water ordinances require the control of both runoff volume and quality. Infiltration methods such as porous pavement, infiltration pits, and perforated drains are proposed for the control of storm water volume and quality, as well as peak rates.

3.3.6 Storm Water Management. A drainage system for new Government facilities which will discharge directly into a system outside the Government's jurisdiction shall meet the storm water management regulations as required by the governing regulatory agency. Where no storm water management regulations exist, the drainage system designer shall consider the following:

a) Impacts on Storm Water Runoff. Consider the impacts of changes in storm water volume, peak flow rates, and quality in the receiving stream associated with the proposed Government facilities.

b) Mitigation of Adverse Impacts. If it is determined that the proposed Government facilities will increase the likelihood or extent of minor flooding, accelerate erosion, or degrade the water quality of the receiving stream, employ storm water management measures to mitigate these conditions.

3.3.7 Storm Water Management Measures

a) Peak Rate Control. Use peak rate control measures to prevent increases in minor flooding and to prevent overloading existing drainage systems. The primary tool for rate control is the storm water management basin or pond with a controlled outlet structure. Refer to MIL-HDBK-1005/3 for design criteria of embankments and spillway controls. Parking areas may only be used as storage if the facility which the parking area supports is where freezing is not a problem. The mission of an activity should not be impaired by rainwater storage in the parking lot. In no case shall parking and open storage areas designated for contingency and readiness type military vehicles and equipment be used to store storm water. Refer to Urban Land Institute, Water Resources Protection Technology. Use SCS, Urban Hydrology for Small Watersheds, TR-55, for hydrograph procedures for hydrologic calculations.

b) Volume Control. Use volume control measures to prevent the increase of erosion rates in receiving streams, the depletion of groundwater, and minor flooding. Volume control is achieved through infiltration methods such as porous pavement, infiltration basins and trenches, and perforated drains and catch basins. Guidelines for the design of these structures are given in the U.S. Department of Transportation (DOT), TS-80-218, Underground Disposal of Storm Water Runoff - Design Guidelines.

c) Quality Control. Use quality control measures to prevent the increase of pollutant loadings in receiving streams. Most volume control measures will also improve the quality of storm water runoff. Additional measures such as parking lot and street sweeping, catch basin cleaning, and settling ponds are discussed in Urban Land Institute, Water Resources Protection Technology. Naval Civil Engineering Laboratory (NCEL) published a report in August 1989 entitled "Initiation Decision Report: Nonpoint Source Discharge," which identifies the problems caused by Navy nonpoint source discharges, and discusses methods to control and improve storm water runoff quality.

d) Best Management Practices. As an outgrowth of the Federal Water Pollution Control Act Amendments of 1972 (Public Law 92-500), Section 208, several states have published handbooks and design guidelines on the control of storm water quality. These guidelines are called Best Management Practices (BMPs).

Section 4: COASTAL FLOODING AND DRAINAGE

4.1 General Considerations. In addition to riverine flooding, coastal areas are exposed to three other potential flooding elements: astronomical tide fluctuations, storm surge, and wave height. For the purpose of the design of coastal facilities, these elements occur simultaneously and are additive.

4.2 Astronomical Tide Fluctuations. Astronomical tide fluctuations are caused by the gravitational attraction of the moon and sun. Records of daily fluctuations and monthly and seasonal extremes are available for most locations. Refer to Section 7 for sources of tide data.

4.3 Storm Surge. Storm surge is the buildup of water along coastlines and in estuaries due to sustained high winds such as those of cyclonic storms. The magnitude of storm surge is dependent on the velocity, direction, and duration of wind and the configuration of the coastline. Refer to Section 7.

4.4 Wave Height. For calculating wind-generated wave height based on wind velocity, fetch length, and bottom resistance, refer to NAVFAC DM-26.02, Coastal Protection, Sections 5, 6, and 7 and U.S. Army COE, Shore Protection Manual.

4.5 Combined Riverine and Tidal Flooding in Estuaries. Flooding in estuaries is influenced by tides, storm surge, and stream flow. For the combination of these events and the probability of their simultaneous occurrence, refer to the following:

Journal of the Hydraulics Division, "Tidal Computations for Rivers, Coastal Areas and Seas," J. J. Dronkers, 1969.

National Weather Service (NWS), Joint Probability Method of Tide Frequency Analysis Applied to Apalachicola Bay and St. George Sound, Florida, F. P. Ho and V. A. Meyers.

Journal of the Hydraulics Division, "Flood Profiles in Combined Tidal-Freshwater Zones," J. D. Jenkins and H. M. Johnson.

Section 5: INTERIOR DRAINAGE OF LEVEED AREAS

5.1 Interior Drainage. Levees and floodwalls protect Government, residential, industrial, and commercial areas from floods resulting from high stages in a river, lake, or tidal area. Make appropriate provisions for storm water that accumulates within the leveed area. This storm water is labeled interior drainage.

5.2 Hydrologic Considerations. In addition to direct runoff from rainfall, consider the quantity of groundwater flow from aquifers outcropping within the interior drainage area, seepage flow from under and through the levee, sanitary and industrial flows, and wave overtopping.

5.3 Computational Methods. Use hydrograph derivation methods listed in Section 6 and hydrograph routing procedures given in Table I to determine required ponding volume for temporary storage and design of pumping facilities and pressure conduits.

5.4 Detailed Reference. Refer to U.S. Army COE, EM 1110-2-1413, Hydrologic Analysis of Interior Areas.

Section 6: RUNOFF PREDICTION METHODOLOGIES

6.1 Manual Runoff Computational Methods for Small Watersheds. Refer to Table 2 for manual methods and application criteria. For sources of data, see Section 7.

6.2 Computer Runoff Computational Methods. Refer to Table 3 for description of computer models available for runoff computations.

Table 2
Manual Methods of Determining Runoff for Small Watersheds

Methodology	Data Requirements	Application	Limitations	References
Rational Method	Topographic and land use maps, rainfall data (local intensity duration curves)	Open and closed storm drain systems, including rooftop drainage	Drainage area less than 200 acres. Not suitable for hydrograph analysis or storm water management	Water Pollution Control Federation, Manual of Practice No. 9, Design and Construction of Sanitary and Storm Sewers. Linsley, Kohler, and Paulhus, 1982, Ch. 9
SCS Tabular Method	Topographic, land use, and soils maps, rainfall data (included in TR-55 for United States)	Develop composite hydrographs for watershed from subareas using SCS unit hydrograph procedures	Drainage area 10-2000 acres for each subarea. Curve number variability among subareas must be less than 30. Runoff volume greater than 1.5 inches for curve numbers less than 60.	SCS, TR-55.
SCS Graphical Method"	Topographic, land use, and soils maps, rainfall data (included in SCS, TR-55 for United States)	Peak discharge determinations based on time of concentration	Drainage area 10-2000 acres. No runoff hydrograph, peak flow rate only	SCS, TR-55.

Table 2 (Continued)
Manual Methods of Determining Runoff for Small Watersheds

Methodology	Data Requirements	Application	Limitations	References
SCS Chart Method	Topographic, land use, and soils maps, rainfall data (included in SCS, TR-55 for United States)	Peak discharge determinations based on watershed slope. Adjustments for watershed shape, ponds, swamps, impervious areas, and channel modifications	Drainage area 10-2000 acres. Peak flow rate only. No runoff hydrograph. No valley or reservoir routing	SCS, TR-55.

Table 3
List of Computer Models

Subject	Title	Description	Source
Rainfall/Runoff/ Hydrograph Models	1. HEC-1, Flood Hydrograph Package Unit Hydrograph Computation (UHCOMP), Interactive Unit Hydrograph and Hydrograph Computation	Develops runoff hydrographs using Clark, Snyder, SCS, or actual unit hydrographs; derives unit hydrographs and optimizes loss-rate functions. Several reach and reservoir routing options; combines hydrographs from subareas.	U.S. Army COE, HEC, Davis, Ca., (916) 756-1104
	2. SCS, TR-20	Develops runoff hydrographs using SCS dimensionless unit hydrograph procedures, uses reach and reservoir routing, and combines hydrographs. Use 0.1 hr increment rainfall table for total watershed area between 10 and 400 acres.	U.S. Dept. of Agriculture, SCS, Engineering Division, (202) 447-2520
Runoff Quality Models	1. HEC, Water Quality for River-Reservoir Systems (WQRRS)	Models impact of pollutant loadings on river-reservoir systems.	HEC
	2. Simulation of Flood Control of Conservation Systems with Water Quality, HEC-5Q	Models reservoir systems with water quality analysis.	HEC
	3. Scour and Deposition in Rivers and Reservoirs, HEC-6	Sediment transport model.	HEC

Table 3 (Continued)
List of Computer Models

Subject	Title	Description	Source
	4. U.S. Environmental Protection Agency (EPA), Storm Water Management Model (SWMM)	Models quantity and quality of runoff from urban areas and impact of pollution control measures.	EPA, Environmental Research Lab, Athens, Ga (404) 546-3154
	5. HSPF, Hydrologic Simulation Program - FORTRAN	Models quantity and quality of runoff from agricultural land and impact of BMPs.	EPA, Environmental Research Lab, Athens, Ga. (404) 546-3154
Statistical Models	Flood Flow Frequency Analysis	Computes probability of exceeding, recurrence intervals, and graphical output.	HEC
Water Resources Models	HEC-5Q	Models reservoir systems for flood control and conservation storage requirements. Computes expected annual flood damages, system costs, and system net benefits.	HEC

Section 7: SOURCES OF DATA

7.1 Rainfall. Refer to Table 4 for sources of available rainfall data.

a) Locations Not Covered by National Oceanic and Atmospheric Administration (NOAA) Publications. To construct rainfall intensity-duration-frequency curves for foreign locations not covered by NOAA publications, obtain available information from local governments and other sources. Use the method described in NWS, Technical Paper No. 40 (TP-40), Rainfall Frequency Atlas of the United States for Durations From 30 Minutes to 24 Hours and Return Periods From 1 to 100 Years, for deriving curves.

7.2 Stream Gages. Published stream flow data is available for each state from the U.S. Geological Survey (USGS). These are in the form of Surface Water-Supply Papers which include mean daily and monthly summary discharge records. The headquarters of USGS is located at 12201 Sunrise Valley Drive, Reston, VA 22092.

The U.S. Department of Agriculture, Soil Conservation Service (SCS), publishes stream flow data from plots and small watersheds in SCS technical papers, technical bulletins, and hydrologic bulletins. Contact Chief, Hydrology Branch, Engineering Division, Soil Conservation Service, P.O. Box 2890, Washington, DC 20013.

7.3 Meteorological Data. Data is available from the following agencies:

National Weather Service, Office of Hydrology, 1325 East-West Highway, Silver Spring, MD 20910

Department of Transportation, 400 Seventh Street, S.W., Room 2318, Attn: M-443.2, Washington, DC 20590

7.4 Tides. Obtain tidal information from the National Ocean Service/NOAA, Tidal Datum Quality Assurance Section, Code N/OMA123, 6001 Executive Boulevard, Rockville, MD 20852. Tide data for selected U.S. Naval facilities is given in NAVFAC DM-26.01, Harbors, Section 2, Basic Planning.

7.5 Groundwater. Field measurements and investigations of groundwater have been conducted in the United States mainly by the USGS in cooperation with individual states. This information is available as published circulars, professional papers, and water supply papers. See USGS, Circular 777, A Guide to Obtaining Information From the USGS. Groundwater measurements in key observation wells have been published by the USGS under the title of Groundwater Levels in the United States.

a) Computerized Water Data. The National Water Data Storage and Retrieval System (WATSTORE) was established by the USGS in 1971 to provide a large scale computerized system for the storage and retrieval of water data. Data is available to the public through district offices.

b) State Publications. State geological and water resources agencies may also provide data on groundwater in the state.

c) Professional Journals. There is a vast amount of professional literature available on ground water, including the International Association of Hydrological Sciences, Hydrological Sciences Journal and the serials, the National Water Well Association, Groundwater.

7.6 Land Use. LANDSAT satellite data, high-altitude photography, and low-altitude aerial photography mapping is available from the USGS's Earth Resources Observation System (EROS) Data Center, Mundt Federal Building, in Sioux Falls, SD 57198. Maps of various types can be obtained from National Cartographic Information Center, National Headquarters, USGS, 507 National Center, Reston, VA 22092.

7.7 Soils. The SCS offices have soil surveys for counties in their state. These surveys include maps showing the types of soils and a description of the hydrologic, agricultural, and engineering characteristics.

7.8 Flood Maps. The Federal Emergency Management Agency (FEMA) has flood plain mapping delineation available for streams and for coastal areas. Contact Federal Emergency Management Agency (FEMA), Flood Insurance Administration, 6930 Sand Thomas Road, Baltimore, MD 21227-6227.

7.9 Storm Surge. Data is available from the following sources:

a) U.S. Army Coastal Engineering Research Center, Shore Protection Manual, Section 3.86.

b) Joint Probability of Astronomical Tide and Cyclonic Storms. Refer to Journal of the Waterway, Port, Coastal and Ocean Division, "Joint Occurrences in Coastal Flooding," M. A. Tayfun, 1979.

c) Available Data. Storm surge elevations for many coastal areas of the United States are available from FEMA, U.S. Army COE, and the National Hurricane Center, (NHC).

d) Computer Models. Information on computer models (such as "SLOSH") used for predicting storm surges is available from the National Weather Service, Techniques Development Laboratory, W/OSD 22; the U.S. Army COE; and NHC.

Table 4
Sources of Rainfall Data

Source/Title	Date
Local	
NCDC, Local Climatological Data	Updated monthly

Table 4 (Continued)
Sources of Rainfall Data

Source/Title	Date
NCDC, Monthly Averages of Temperature and Precipitation for State Climatic Divisions 1941-1970	1973
Contiguous United States	
NWS, TP-40	1961
NWS, HYDRO-35, Greatest Known Areal Storm Rainfall Depths for the Contiguous United States	1976
Eastern and Central United States	
NWS, HYDRO-35, Five to Sixty Minute Frequency for Eastern and Central United States	1977
Western United States	
NWS, NOAA Atlas No. 2, Precipitation Frequency Atlas of the Western United States	1973
Alaska	
NWS, Technical Paper No. 47 (TP-47), Probable Maximum Precipitation and Rainfall-Frequency Data for Alaska for Areas to 400 Square Miles, Duration of 24 Hours and Return Periods From 1 to 100 Years	1963
Hawaiian Islands	
NWS, Technical Paper No. 43 (TP-43), Rainfall Frequency Atlas of the Hawaiian Islands for Areas to 200 Square Miles, Duration of 24 Hours and Return Periods From 1 to 100 Years	1962
Storm Drainage Standards, Department of Public Works, City and County of Honolulu, Department of Plans	
Puerto Rico and the Virgin Islands	
NWS, Technical Paper No. 42 (TP-42), Generalized Estimates of Probable Maximum Precipitation and Rainfall Frequency Data for Puerto Rico and the Virgin Islands	1961
Rainfall Intensity-Duration-Frequency Curves	
NWS, Technical Paper No. 25 (TP-25), Rainfall Intensity-Duration-Frequency Curves for Selected Stations in the United States, Alaska, Hawaiian Islands, and Puerto Rico	1955

REFERENCES

NOTE: Unless otherwise specified in the text, users of this handbook should utilize the latest revisions of the documents cited herein.

FEDERAL/MILITARY SPECIFICATIONS, STANDARDS, BULLETINS, HANDBOOKS, NAVFAC GUIDE SPECIFICATIONS:

The following specifications, standards, bulletins, and handbooks form a part of this document to the extent specified herein. Unless otherwise indicated, copies are available from the Standardization Document Order Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

HANDBOOKS

MIL-HDBK-1005/3	Drainage Systems
MIL-HDBK-1005/7	Water Supply Systems
MIL-HDBK-1190	Facility Planning and Design Guide

NAVY MANUALS, P-PUBLICATIONS, AND MAINTENANCE OPERATING MANUALS: Available from Commanding Officer, Naval Publications and Forms Center (NPFC), 5801 Tabor Avenue, Philadelphia, PA 19120-5099. To order these documents: Government agencies must use the Military Standard Requisitioning and Issue Procedure (MILSTRIP); the private sector must write to NPFC, ATTENTION: Cash Sales, Code 1051, 5801 Tabor Avenue, Philadelphia, PA 19120-5099.

DM-26.01	Harbors
DM-26.02	Coastal Protection
P-73	Real Estate Procedural Manual

OTHER GOVERNMENT DOCUMENTS AND PUBLICATIONS:

The following Government documents and publications form a part of this document to the extent specified herein.

Public Law 92-500, Amendments Section 208	Federal Water Pollution Control Act of 1972 as Amended

(Available from Environmental Protection Agency (EPA), 401 M Street, S.W., Legislative Library A-102, Washington, DC 20460)

U.S. ARMY COASTAL ENGINEERING RESEARCH CENTER

Shore Protection Manual, 4th ed., Volumes I and II, 1984.

(Available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402)

U.S. ARMY CORPS OF ENGINEERS (COE)

Cost Report on Non-Structural Flood Damage Reduction Measures for Residential Buildings Within the Baltimore District, July 1977.

(Available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161)

U.S. ARMY COE

Carson, W. D. (1975), Estimating Costs and Benefits for Nonstructural Flood Control Measures.

Owens, H. J. (1977), Annotations of Selected Literature on Nonstructural Flood Plain Management Measures.

HEC-1	Flood Hydrograph Package
HEC-3	Reservoir System Analysis for Conservation
HEC-5	Simulation of Flood Control of Conservation Systems
HEC-5Q	Simulation of Flood Control of Conservation Systems With Water Quality
HEC-6	Scour and Deposition in Rivers and Reservoirs
WQRRS	Water Quality for River-Reservoir Systems

Hydrologic Engineering Methods for Water Resources Development:

Volume 1	Requirements and General Procedures
Volume 3	Hydrologic Frequency Analysis
Volume 4	Hydrograph Analysis
Volume 8	Reservoir Yield
Volume 10	Principles of Groundwater Hydrology

(Available from U.S. Army Corps of Engineers, Hydrologic Engineering Center (HEC), 609 Second Street, Davis, CA 95616)

U.S. ARMY COE

EM 1110-2-1408	Routing of Floods Through River Channels

EM 1110-2-1413 Hydrologic Analysis of Interior Areas

(Available from U.S. Army Corps of Engineers, Publications Depot, 2803 52nd Avenue, Hyattsville, MD 20781-1102)

U.S. DEPARTMENT OF AGRICULTURE, SOIL CONSERVATION SERVICE (SCS)

TR-20 Project Formulation Hydrology Users Manual

NEH-4 National Engineering Handbook, Section 4, Hydrology

TR-55 Urban Hydrology for Small Watersheds

Engineering Field Manual for Conservation Practices

(Available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161)

U.S. DEPARTMENT OF THE INTERIOR

Design of Small Dams

(Available from Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402)

Circular No. 900 A Guide to Obtaining Information From the USGS.

Circular No. 856 Storage and Retrieval of Groundwater Data at the USGS.

(Available from U.S. Department of the Interior, U.S. Geological Survey (USGS), Book and Report Sales, Box 25425, Denver, CO 80225)

U.S. DEPARTMENT OF TRANSPORTATION

TS-80-218 Underground Disposal of Storm Water Runoff - Design Guidelines.

(Available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161)

U.S. ENVIRONMENTAL PROTECTION AGENCY (EPA)

Stormwater Management Model (SWMM)

(Available from the National Technical Information Service, 5285 Port Royal Road, Spring, VA 22161)

NON-GOVERNMENT PUBLICATIONS:

The following publications form a part of this document to the extent specified herein. Unless otherwise indicated, the issues of the documents which are DOD adopted are those listed in the Department of Defense Index of Specifications and Standards (DODISS):

Cheney, P. B. and Miller, H. C. (1975), The Application of Nonstructural Measures to Coastal Flooding, Cheney, Miller, Ellis, and Associates, Inc., Putnam, CT, available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

Chow, V. T. (1964), Handbook of Applied Hydrology, McGraw-Hill, New York, NY 10036.

International Association of Hydrological Sciences, Hydrological Sciences Journal, Blackwell Scientific Publications Limited, Osney Mead, Oxford OX2OEL, England (published quarterly).

Linsley, R. K., Kohler, H. A., and Paulhus, J. L. H. (1982), Hydrology for Engineers, 3rd Edition, McGraw-Hill, New York, NY 10036.

Todd, D. K. (1980), Groundwater Hydrology, 2nd Edition, John Wiley & Sons, 1 Wiley Drive, Somerset, NJ 08875.

AMERICAN SOCIETY OF CIVIL ENGINEERS (ASCE)

Dronkers, J. J. (1969), Journal of the Hydraulics Division, "Tidal Computations for Rivers, Coastal Areas and Seas," ASCE, Vol. 95, No. HY1, Proceedings Paper 6341.

Jenkins, J. D. and Johnson, H. M. (1978), Journal of the Hydraulics Division, "Flood Profiles in Combined Tidal-Freshwater Zones," ASCE, Volume 104, No. HY6.

Tayfun, M. A. (1979), Journal of the Waterway, Port, Coastal and Ocean Division, "Joint Occurrences in Coastal Flooding," ASCE, Vol. 105, No. WW2, Proceedings Paper 14560.

Book No. 480	Storm Water Detention Outlet Control Structures.

(Available from American Society of Civil Engineers (ASCE), 345 E. 47th St., New York, NY 10017)

NATIONAL CLIMATIC DATA CENTER (NCDC)

Local Climatological Data (updated monthly)

Monthly Averages of Temperature and Precipitation for State Climatic Divisions 1941-1970

(Available from National Climatic Data Center (NCDC), Federal Building, Asheville, NC 28801-2696)

NATIONAL HURRICANE CENTER (NHC)

Data on storm surge elevations for coastal areas of the United States and on storm surge prediction models:

(Available from National Hurricane Center (NHC), 1320 South Dixie Highway, Room 631, Coral Gables, FL 33146)

NATIONAL WATER WELL ASSOCIATION

Groundwater, Volume 28

(Available from National Water Well Association, 6375 Riverside Drive, Dublin, OH 43017)

NATIONAL WEATHER SERVICE (NWS)

Ho, F. P. and Myers, V. A. (1975), Joint Probability Method of Tide Frequency Analysis Applied to Apalachicola Bay and St. George Sound, Florida.

HYDRO-33	Greatest Known Areal Storm Rainfall Depths for the Contiguous United States, 1976.
HYDRO-35	Five to Sixty Minute Frequency for Eastern and Central United States, 1977.
TP-25	Rainfall Intensity-Duration-Frequency Curves for Selected Stations in the United States, Alaska, Hawaiian Islands and Puerto Rico, 1955.
TP-40	Rainfall-Frequency Atlas of the United States for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years, 1961.
TP-42	Generalized Estimates of Probable Maximum Precipitation and Rainfall-Frequency Data for Puerto Rico and the Virgin Islands, 1961.
TP-43	Rainfall-Frequency Atlas of the Hawaiian Islands for Areas to 200 Square Miles, Duration of 24 Hours and Return Periods from 1 to 100 Years, 1962.
TP-47	Probable Maximum Precipitation and Rainfall-Frequency Data for Alaska for Areas

to 400 Square Miles, Duration of 24 Hours and Return Periods from 1 to 100 Years", 1963.

NOAA Atlas No. 2 — Precipitation Frequency Atlas of the Western United States, 1973.

(Available from National Weather Service (NWS), Office of Hydrology, 1325 East-West Highway, Silver Spring, MD 20910)

URBAN LAND INSTITUTE

Water Resources Protection Technology, "A Handbook of Measures to Protect Water Resources in Land Development," 1981, available from Urban Land Institute, 1090 Vermont Avenue, N.W., Washington, DC)

U.S. WATER RESOURCES COUNCIL

Guidelines for Determining Flood Flow Frequency, Bulletin 17, 1976 and Bulletin 17A, 1977. (Available from U.S. Water Resources Council, 2120 L Street, N.W., Washington, DC)

WATER POLLUTION CONTROL FEDERATION

Manual of Practice No. 9 — Design and Construction of Sanitary and Storm Sewers, 1970.

(Available from Water Pollution Control Federation, 601 Wythe Street, Alexandria, VA 22314-1994)

GLOSSARY

Aquifer. A body of geologic strata that acts as a hydrologic unit and is capable of transmitting significant quantities of water.

Base Flow. Stream discharge derived from groundwater sources; many include flow from regulated lakes or reservoirs.

Drawdown. The distance the water table is lowered by the pumping of a well.

Evapotranspiration. Loss of water from the soil, both by evaporation and by transpiration from the plants growing thereon.

Fetch. The distance along open water over which the wind blows.

Flood Plain. Any land susceptible to being inundated by flood water.

Flood Plain Management. The operation of an overall program of corrective and preventive measures for reducing flood damages, including but not limited to emergency preparedness plans, flood control works, and development regulations.

Floodproofing. Any combination of structural additions, changes, or adjustments to structures which reduces or eliminates flood damage.

Hydrograph. A graph showing, for a given point on a stream or for a given point in a drainage system, the discharge of water with respect to time.

Hydrology. The science dealing with the properties, distribution, and circulation of water on the surface of the land, in the soil and underlying rocks, and in the atmosphere.

Imperviousness. The degree of preventing entrance or passage of water by a given material.

Infiltration. Movement of water through the soil surface into the ground.

Levee. An embankment for preventing flooding.

Reach. Any length of channel, channel bank, stream, river, or shore line selected for convenience in study.

Recurrence Frequency. The frequency per year with which an event of a given magnitude can be expected to be equalled or exceeded. For example, an event with a recurrence frequency of 0.01 will be equalled or exceeded, on the average, once in 100 years.

Recurrence Interval. The average interval of time between values more extreme than a specific magnitude. Reciprocal of the recurrence frequency.

Reservoir. A pond, lake, tank, basin, or other space, either natural or created, which is used for storage, regulation, and management of water.

Routing. The calculation of rates of flow and time increments at specific locations in streams or structures during the passage of floods.

Runoff. The portion of rainfall and snow melt which runs off a drainage area.

Spillway. A passage serving a dam or reservoir through which surplus water may be discharged.

Storm Surge. A rise above normal water level on a coastline or within an estuary or large lake due to the action of sustained high winds.

Tide. The periodic rising and falling of the surface of oceans, seas, and bays, rivers, etc., which results from the gravitational attraction of the moon, sun, and other astronomical bodies acting upon the rotating earth.

Tidal Range. The difference in height between high and low waters.

Water Resources Development. The quantity prediction of water available for consumption, irrigation, power supply, and other uses.

Wave Height. The vertical distance between the wave crest and the preceding trough.

CUSTODIAN
NAVY - YD

PREPARING ACTIVITY
NAVY - YD

PROJECT NO.
FACR - 0761